Edgewood Chemical Biological Center

Air Flow Patterns Around Several Biological Point Detection System Configurations

Daniel G. Wise, Daniel J. Weber, Donna L. Carlile

Research Directorate
U.S. Army Edgewood Chemical Biological Center (ECBC)
Aberdeen Proving Ground, Maryland

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Introduction

Current bio-defense point detection systems depend on acquiring a sample of the ambient aerosol.

The aerosol inlet to the collection system is therefore a primary component & crucial to the performance of the entire point detection system.

Flow field around and to an inlet intake is important issue when considering the performance of a point detection system

Inlet placement with respect to other objects in the flow field can have an impact on the performance of the system.

For example:

- The inlet could be sampling from recirculation zones where interferents accumulate
- The inlet may be in a flow field where the ambient aerosol cannot be directly aspirated
- There could be local flow accelerations or vectoring to inlet at non-design orientations

Background

•The subject of flow field near inlets is applicable to any collector system used for a variety of purposes (environmental, health& safety, Homeland Security, Bio-Defense).

•JBPDS was the particular system used in this study.

- •high flow rate wetted wall cyclone used to collect aerosol samples.
- •samples analyzed by assay to identify bio-agents.
- •fluorescence based particle analyzer (BAWS) used as a trigger device to manage consumables.

Background

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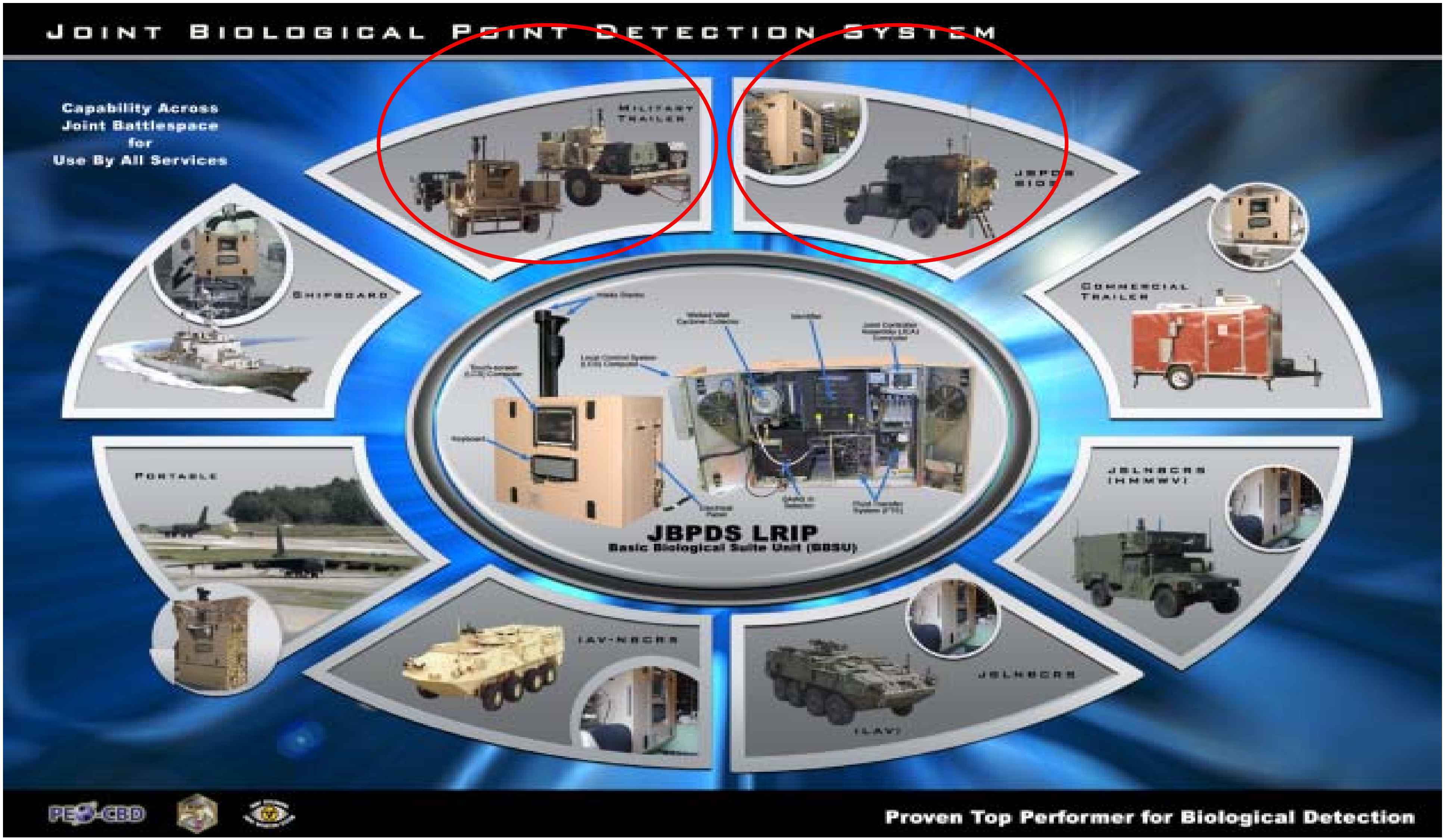
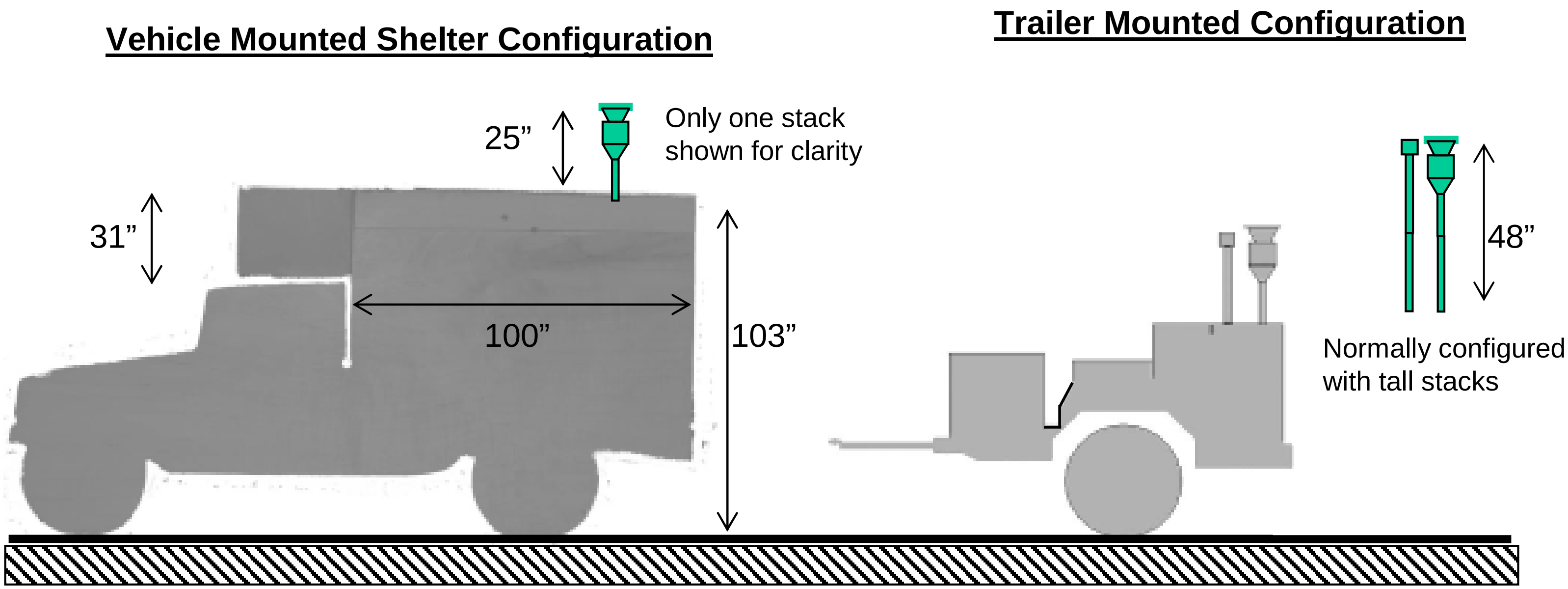
JBPDS, All Services, Many Platforms



Silhouettes of JBPDS Configurations Considered

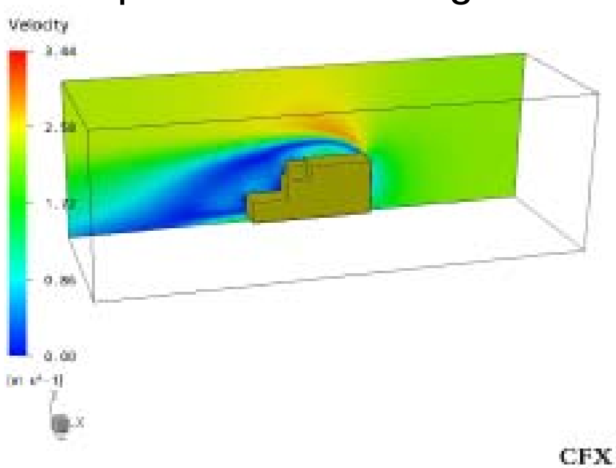


Background

Question: Inlet position is fixed by interior component layout, what is a good inlet height to insure the trigger obtains a good sample from ambient air at personnel level without aspirating interferents from ground.

Approach: Evaluate flow over Vehicle & Trailer config.

- Flow Visualization
  - Scale models in wind tunnels
  - Actual JBPDS in breeze tunnel (trailer)
  - Actual JBPDS in outside breeze (vehicle)
- Simple CFD modeling



Background

Wind tunnel testing vs Full scale testing

- Actual JBPDS is large. Requires large test facility
  - Difficult to produce controlled environment necessary for good flow visualization. (streamlines)
- Wind tunnel testing using scale models is a standard practice as an alternative to full scale testing.
  - Flow patterns over scale models should be the same as full scale patterns if Reynolds numbers (ratio of inertial to viscous forces) are maintained.

$$\mathrm{Re} = \frac{V\,d}{\nu}$$

Background: Wind tunnel testing vs Full scale testing

Vehicle Mounted Configuration

•Full Scale Re= 318K at 4-mph,

•Wind tunnel scale and test velocity chosen to match Re

- •Compromise test issues such as test section blockage and smoke dilution with increasing wind speed.
- •In our facilities flow visualization is best conducted in the 20-40 mph range
- •Test section blockage below 10%.

• 8% scale model was chosen and test velocity was in the 20-mph range for best photography of streamlines (blockage=9% CFD used to show flow patterns unaffected)

•Wind tunnel Re= 130K at 20-mph (for non-laminar flow this would be considered a similar flow regime as the 318K full scale vehicle in a breeze).

- •Previous flow visualization work shows Reynolds number independence in test velocity range of 20 to 75-mph

Also, to supplement the wind tunnel study we tried open air testing of actual JBPDS vehicle using ambient breeze. This is was minimally successful, but some important observations did result and are presented subsequent to the results of the wind tunnel study.

Background: Wind tunnel testing vs Full scale testing

Trailer Mounted Configuration

- Trailer mounted version is smaller than Vehicle mounted version.
  - Tested scale model in wind tunnel (Scale: 20% Re=127K at 20mph)
  - Tested in large breeze tunnel (V=4-mph, Re=127K)

Details of wind tunnel facility

Subsonic Wind Tunnel

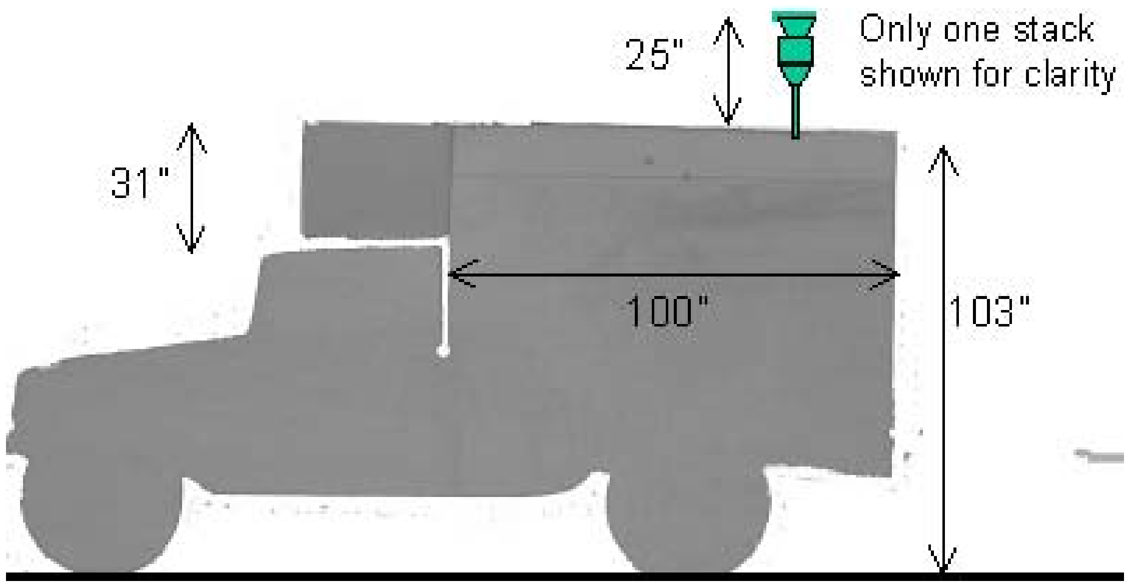
- 28x40-inch test section
- 3 Configurations
  - Generic aerosol mixer insert for sampler inlet efficiency studies 10-60-mph
  - Aerosol Confinement Sleeve Insert for UAV or high speed inlet studies (10-140 mph)
  - Clean Tunnel for aerodynamic testing (flow, force,& moment) (10-140 mph)

Test Equipment

Flow visualization with smoke wand (Nutem –no longer available). Images recorded with hi-8 video, digital video, and digital still camera

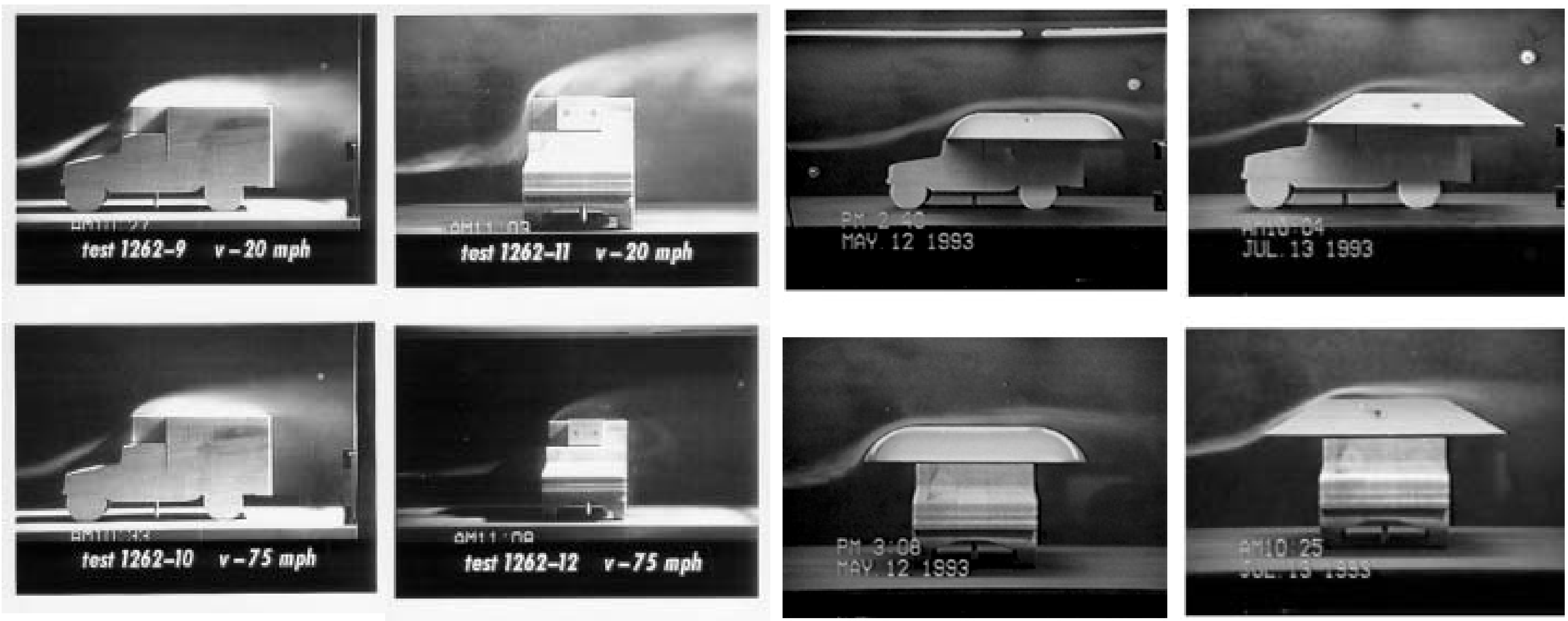
Part 1: JBPDS Mobile Shelter Version

Vehicle Mounted Shelter Configuration



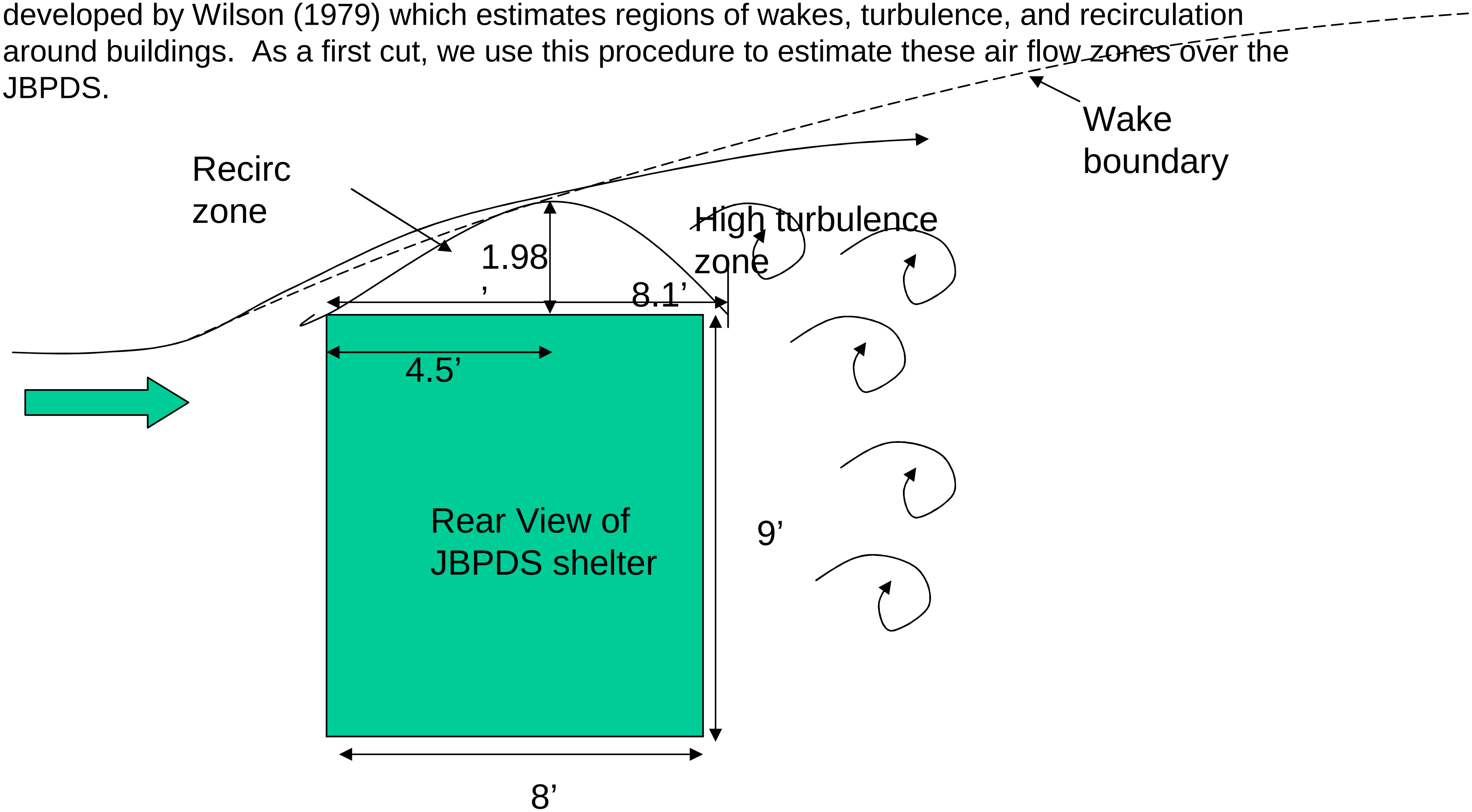
Historical Background:

Flow over a BIDS vehicle was studied in 1993 using 8% scale model. Various awning-type attachments to the shelter were modeled in an attempt to reduce the recirculation and wake zones to improve airflow to the inlets. A curved awning worked very well, but would be cumbersome to implement on actual vehicle. A straight awning that would be simpler to implement was tested. Flow was not as nice as curved awning, but better than no awning. These awnings were modeled as solid material, not porous netting as employed current JBPDS system. Also note that the awning angle appears to be shallower than the angle of deployed camo net.



Preliminary Calculations: estimate flow zones

ASHRAE handbook details design procedure for required stack height to avoid contamination developed by Wilson (1979) which estimates regions of wakes, turbulence, and recirculation around buildings. As a first cut, we use this procedure to estimate these air flow zones over the JBPDS.



Details of wind tunnel model

Actual JBPDS

Actual JBPDS Camouflage net

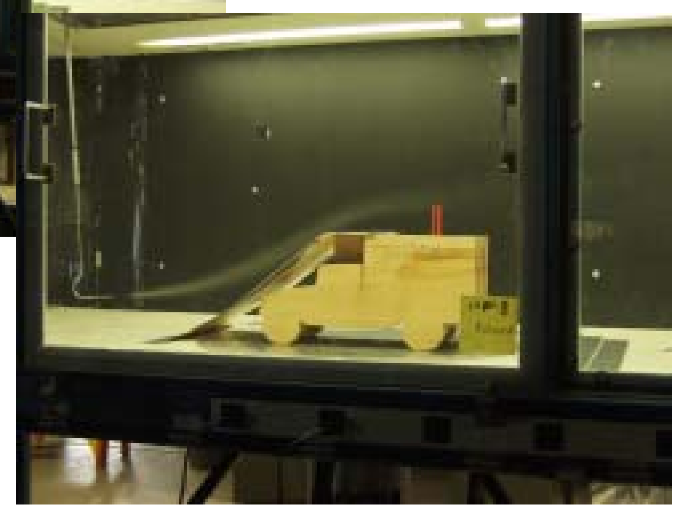
JBPDS model 1:12.5 (8%) scale

JBPDS model w/ screen simulating camo net

Test Configurations

JBPDS operations dictate use of camo net. Could affect airflow. Hard to assure correct modeling in scale. So test at extremes and best guess model, ie: without net, with fine mesh screen fabric to match full scale porosity test, and with non-porous net.

Test at forward facing orientation (SOP for JBPDS deployment) and Side to wind with inlets on lee side (worst case for airflow to inlet)



No camo net

Camo net modeled with screen mesh

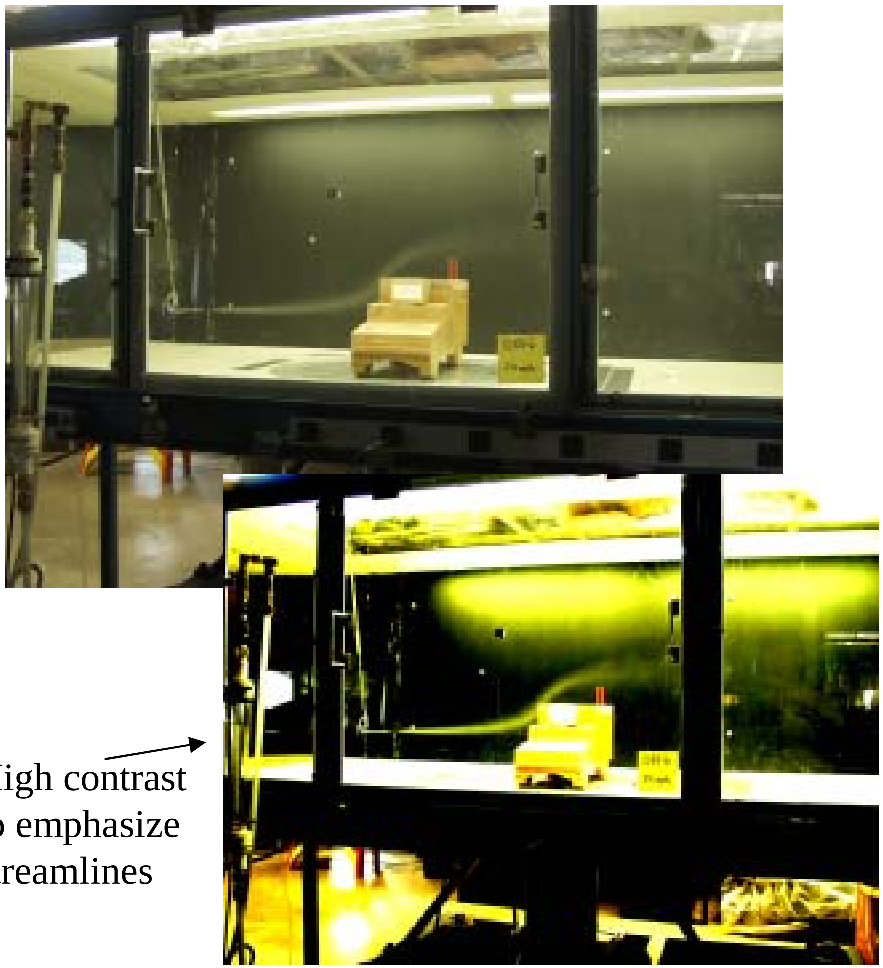
Non-porous camo net model

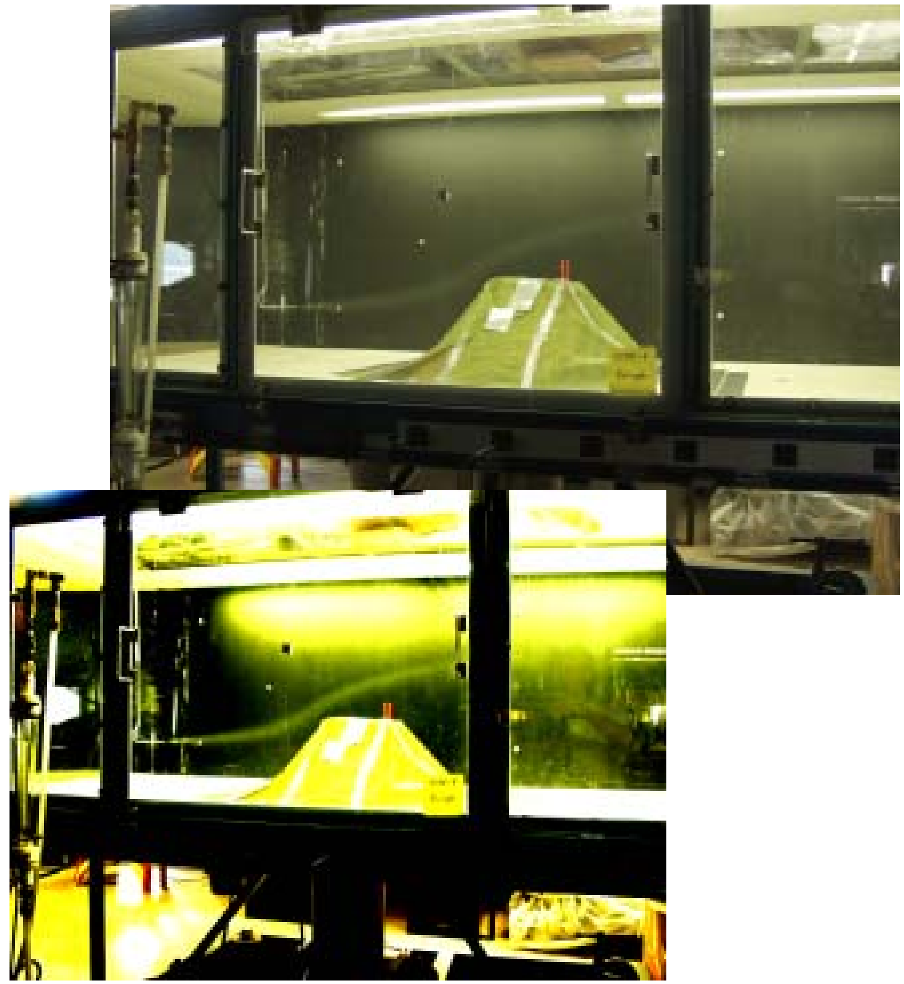
Analysis

Convert photos to high contrast to emphasize streamlines

Measure flow regions from photos

Back-trace streamlines from inlet height to free-stream height (effective sampling height)

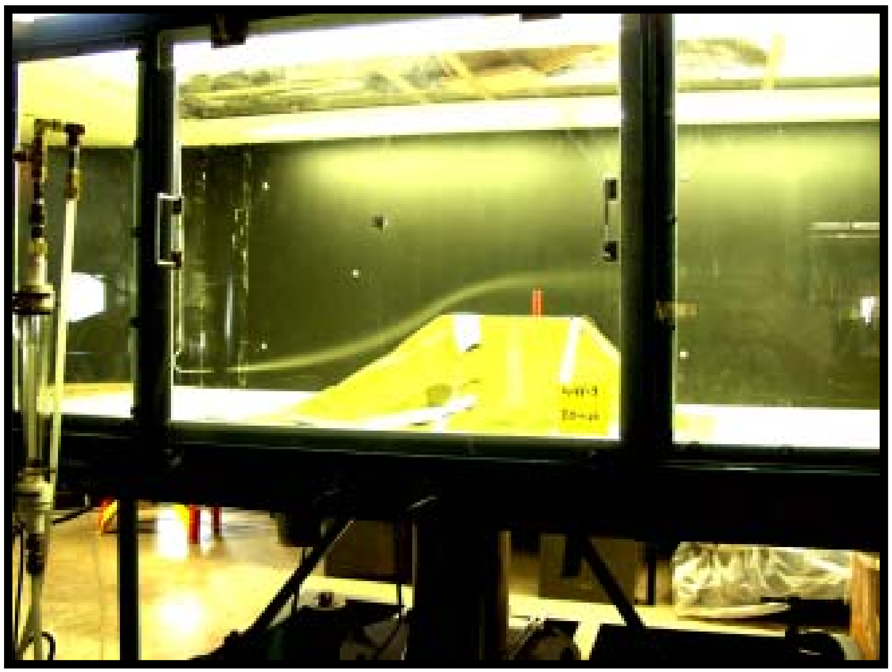


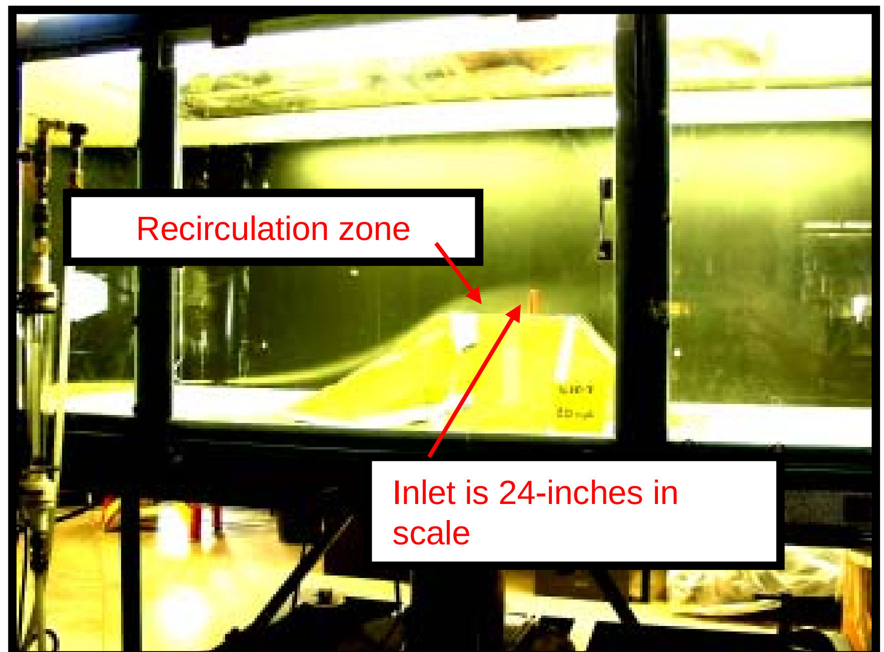


High contrast to emphasize streamlines

Example of analysis

Forward facing, scaled camo (screen fabric)





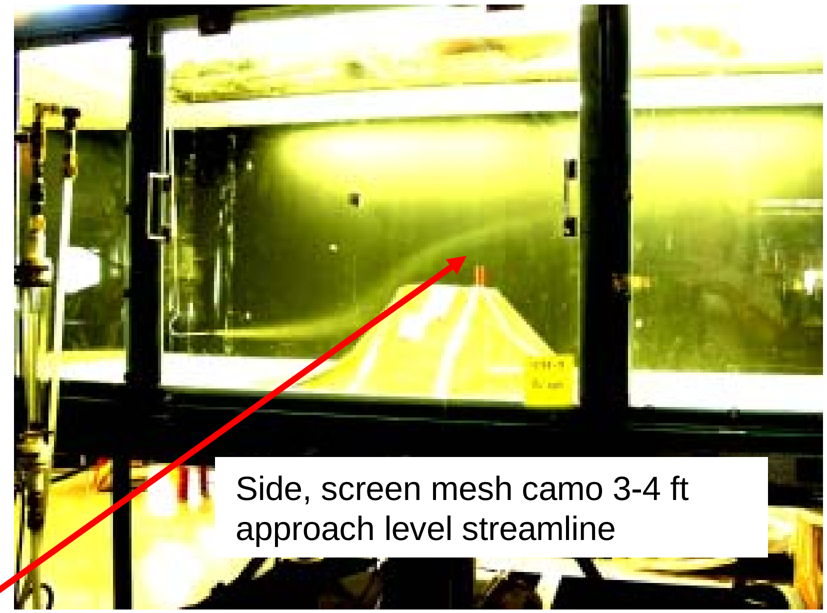
Flow from 3.5-ft approach level is directed over inlet

Flow from 2-ft approach level is directed to inlet recirculation zone

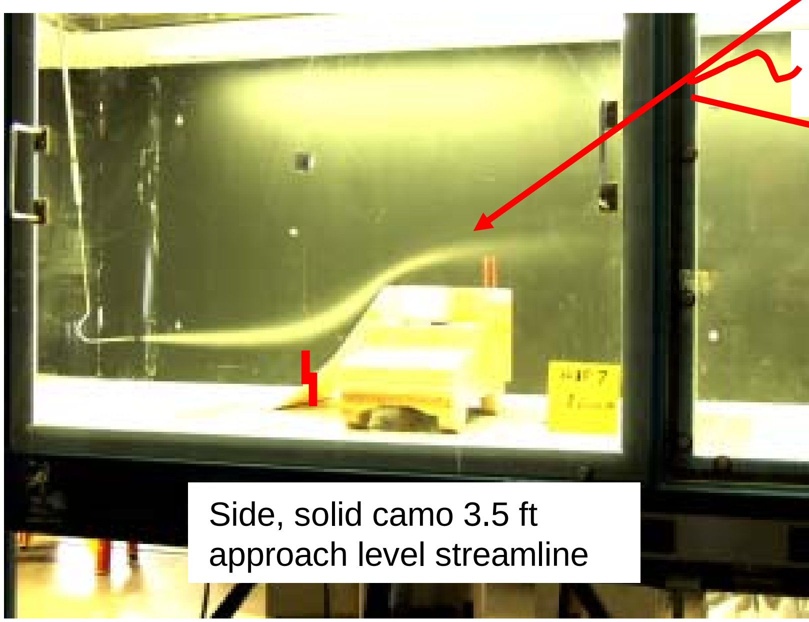
Example of analysis

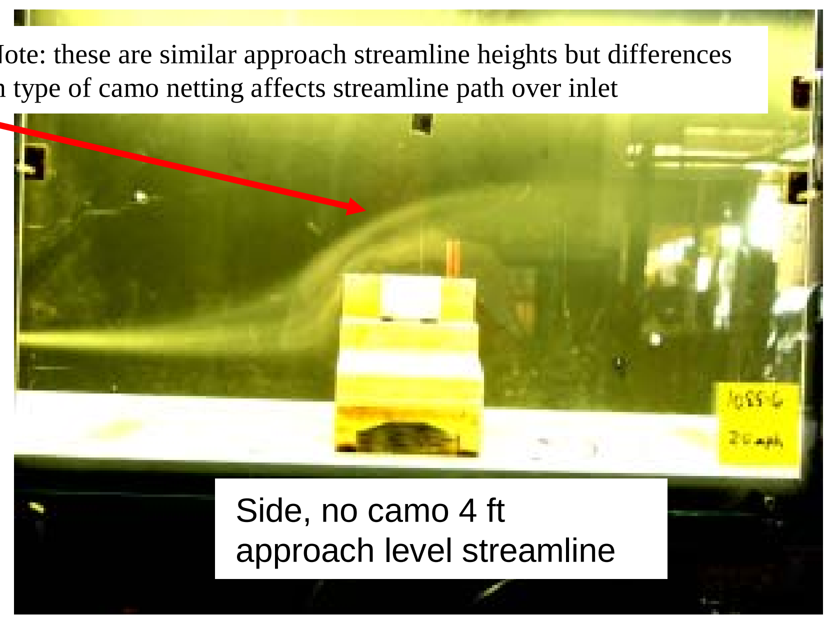
Side forward (worst case flow) with various camo configs and approach streamline heights


Side, solid camo 1-2 ft
approach level streamline


Side, screen mesh camo 3-4 ft
approach level streamline

Note: these are similar approach streamline heights but differences in type of camo netting affects streamline path over inlet


Side, solid camo 3.5 ft
approach level streamline


Side, no camo 4 ft
approach level streamline

Outdoor testing w/ actual JBPDS draped in camo netting

•Very mild breeze test condition (0 to 4-mph)

•Difficult to visualize flow to inlet area, wind was unsteady and turbulent

•No quantitative measurements possible

•Flow was as inclined to go around the object as over the top

•In very light wind the flow would see camo netting as a wall and go around or over

•In heavier winds the flow seemed to go right through the net, and emerge on the lee side of vehicle. Smoke would then persist in the lee wake region of vehicle

Difficult to maintain good smoke visualization

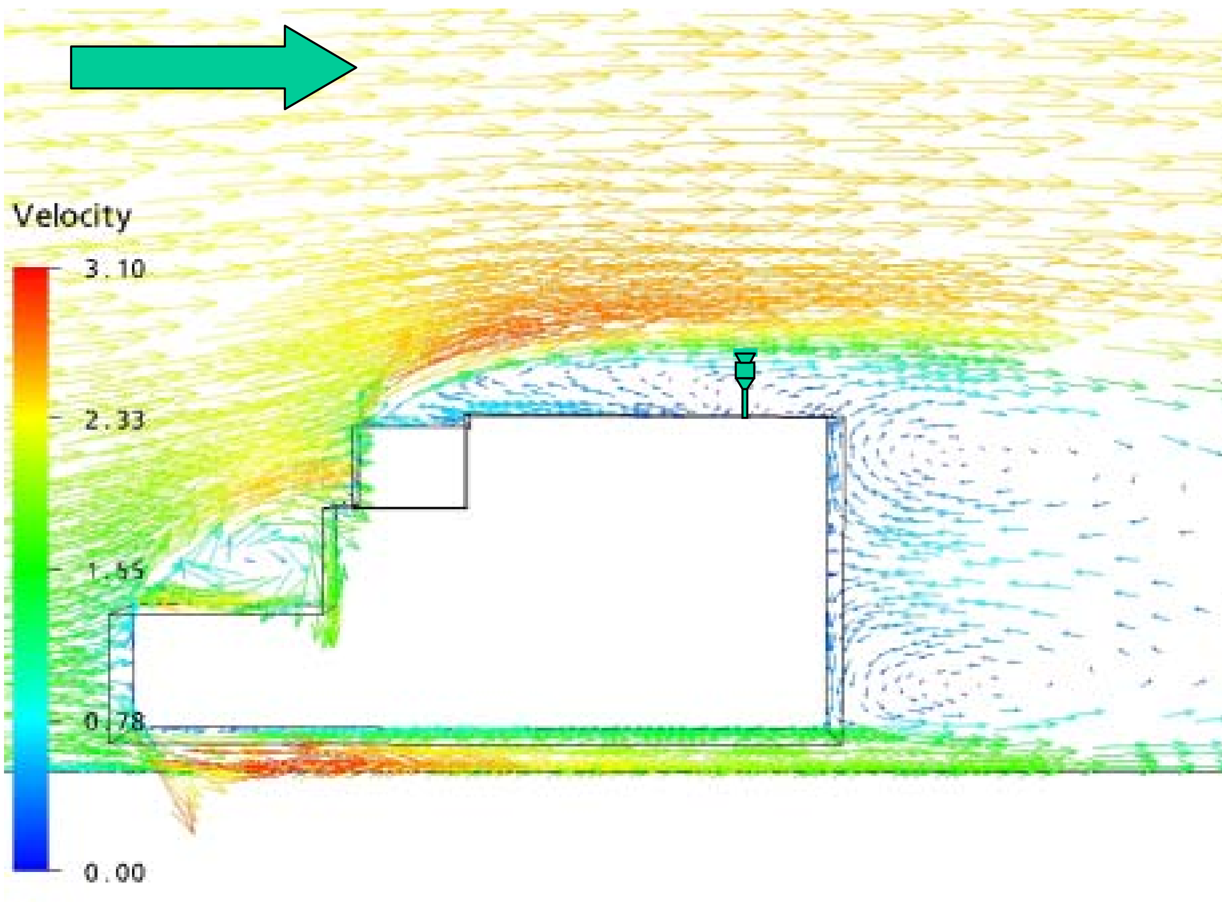
Flow going over vehicle and netting to inlets

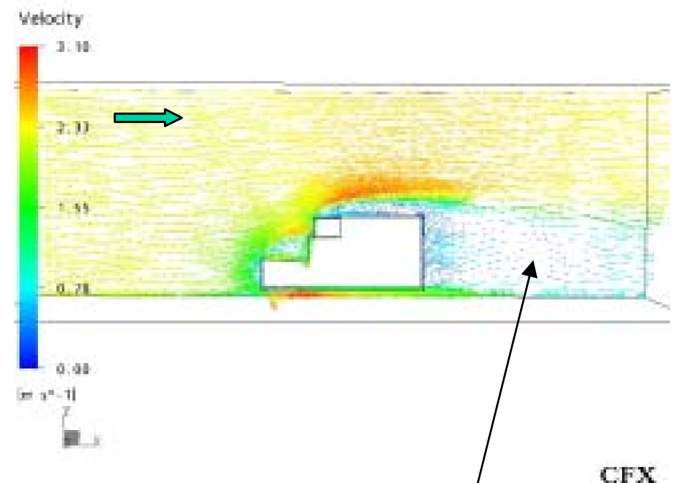
Flow going through netting and emerging/persisting in rear wake area

CFD Modelling

Subsequent to the wind tunnel flow visualization, simple CFD modeling was performed

Flow approaching from front of vehicle





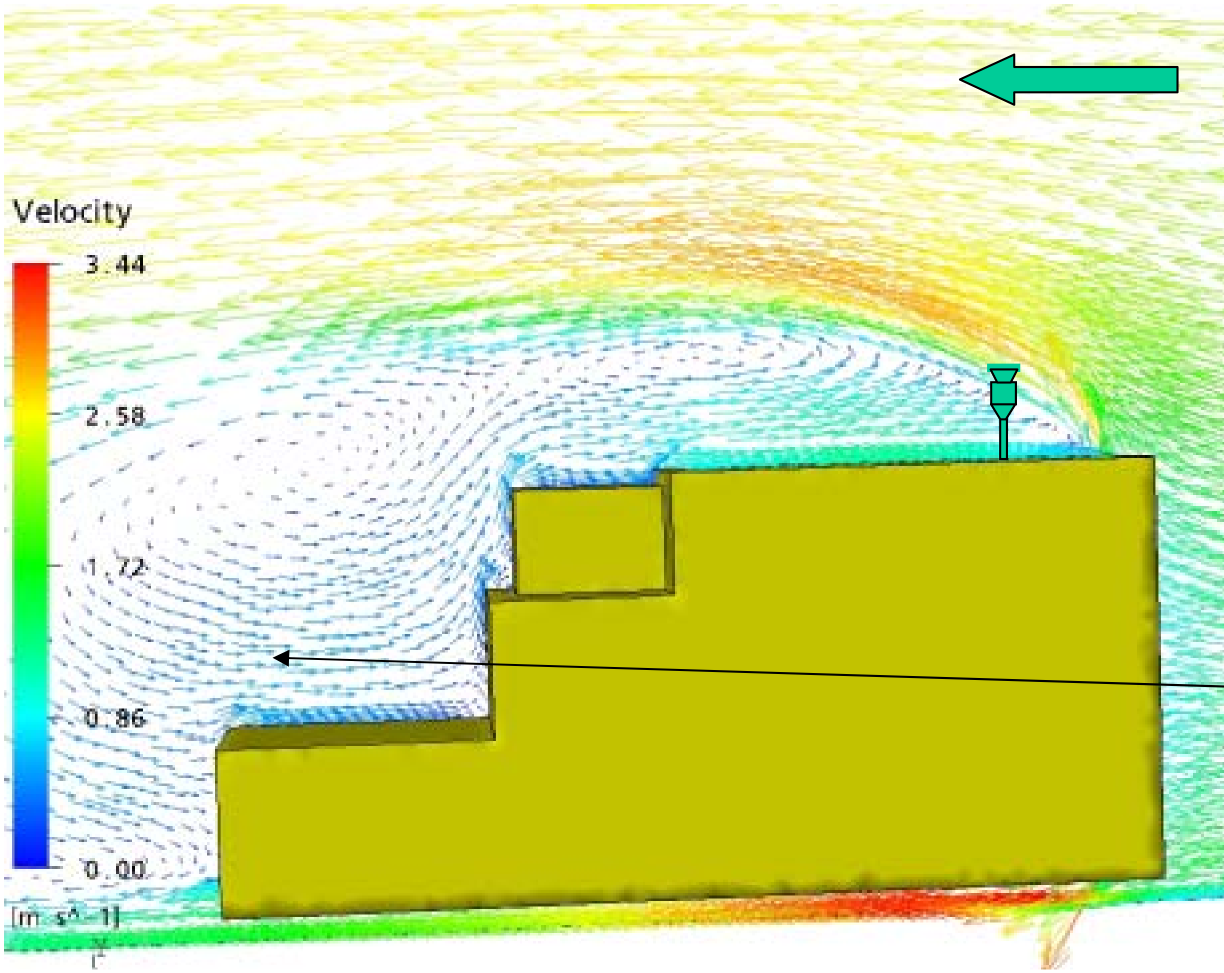
Flow direction split in wake

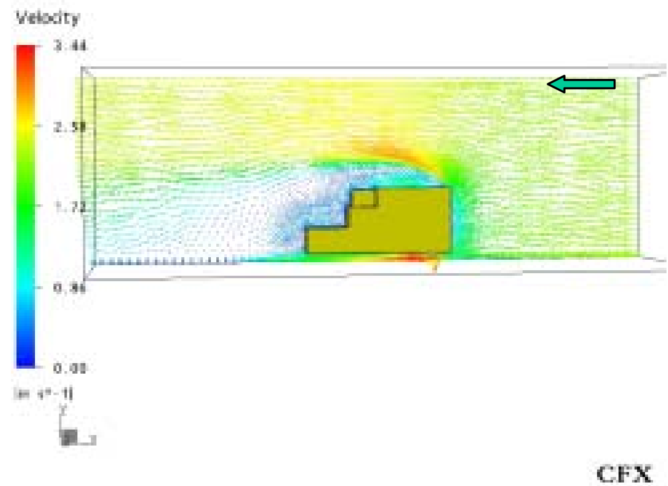
Flow in this area can be drawn back to inlet intake

CFD Modelling

Subsequent to the wind tunnel flow visualization, simple CFD modeling was performed

Flow approaching from rear of vehicle





Flow in this area can be drawn back to inlet intake

Discussion

1. Wind tunnel modeling verified:

- Handbook calculated and CFD predicted flow patterns over simple blocks which approximate the side forward shape of the JBPDS agree well with observed flow patterns. ASHRAE handbook predicts a recirculation zone of ~2 feet high, and observed flow pattern indicates the same in scale.
- CFD and previous flow visualization study confirm flow pattern independence of Reynolds number within the range used in wind tunnel testing.
- Actual camouflage net allows about 80% of flow to pass when oriented on a slant. Screen mesh was used to model this effect in wind tunnel testing.

Discussion

2. Observations from Wind Tunnel Test:

- Different degrees of camouflage netting were used in testing. A solid fabric lessens the blunt shape of the vehicle and allows the flow to more closely follow the roofline, the mesh screen chosen to approximate the real camouflage net mitigates blunt body effects but not nearly as much as solid fabric, no camouflage net at all is worst case in terms of largest recirculation and wake zones. These observations are logical.
- The recirculation zones over the shelter are on the **same order of height as the inlet intakes** (it is unsteady flow and fluctuates plus and minus ~6 inches (full scale).
- In a forward facing orientation (SOP for JBPDS deployment) and configured with the best guess approximation camo netting (mesh screen) the flow from about **4–ft approach level (flow ahead of the vehicle influence) will come closest to the inlet intake and seems to coincide with the upper edge of the recirculation zone.** Flow below this level trips over the leading edge of the shelter and enters the recirculation zone, Flow above this level passes smoothly above the inlet intake.
- In a side facing orientation creates largest recirculation zone. If the inlet is on the forward edge then it is easily in clean air flow, but **if on the lee side, it will be in the recirculation zone**.

Discussion

3. Observations from open field testing of actual JBPDS Vehicle Shelter:

- Hard to get good results due to uncontrollable environment
- **Effect of camouflage net on flow seems to be wind speed dependant.** At low speeds the net appears to deflect the smoke well (like a solid tarp) at higher velocity breezes, the smoke penetrates the netting and lingers underneath, eventually emerging on the lee-side of the vehicle
- **Height of recirculation zone over the roof depends on the angle it approaches vehicle:** In a corner approach there is a very small recirculation zone-curls around edge, whereas **in a broad side approach there is a larger recirculation zone that could be as large as twice the height of inlet.**
- In all cases there was a large dirty wake that lingered behind vehicle for a long time

Discussion

4. Observations from CFD model:

- Showed good agreement with flow visualization
- Showed details of flow not obvious in flow visualization

  Ex: flow in wake regions can be drawn back against ambient flow and directed to inlet intake area. So placing a contaminating source downwind from system does not assure that it will not propagate back to inlet. (lesson: put exhaust tube from generators far beyond reverse flow region)

Part 1. Summary and Comments

- Free stream air from about 3 to 4.5 feet above the ground is directed to inlet intake.
- Boundary of the recirculation zone above the JBPDS shelter vehicle coincides with inlet intake. Flux of particles into this zone is probably less than free stream but they are trapped there and persist and perhaps build up in concentration over time.
- Air flow from ground level is also directed to the roof level and can be entrained in the recirculation zone over the roof.
    - Also, dust that has settled on the net during still air conditions may be re-aerosolized when a breeze kicks up and directed by the flow over the leading edge lip of the shelter into this recirculation zone.
- As the boundary of the recirculation zone fluctuates, the inlet intake sometimes lies within this zone, therefore aspirating the dirtier air. This may be problematic for some trigger systems as it sees a fluctuating background aerosol.
- Contaminants from downwind sources can be drawn back to the inlets via reverse flow in wake and entrained in the recirculation zone

Part 1. Summary and Comments

Should height of inlet be increased?

•Moving the inlet intakes up 2 feet would eliminate the question of flow field effects

•Trigger system would not be adversely affected and would probably see a steadier, less fluctuating particle/contaminant background.

•Collector assays are material specific.

- •Collecting dust along with bioagent not a problem.?
- •Perhaps recirculation zone can increase the local concentration and persistence of aerosol by trapping aerosol particles in the dead air region. *Perhaps* there is some benefit to having collector inlet in this region.
  - •Quick follow on study was performed at Battelle's Ambient Breeze Tunnel facility. STAs were placed in recirculation zone and in free stream. Showed a very slight increase in concentration over roof. Inlet efficiency of STA was elimnated as a variable. However differences were not much above uniformity differences of tunnel. So test not definitive, but adds fodder to the speculation.

Part 2. Trailer Mounted Configuration

Similar issues concerning inlet height have come up for the trailer mounted version of JBPDS. Consequently another series of wind tunnel test using a 20% scale model are planned. In addition, the smaller size of the trailer version allows the use of the ECBC breeze tunnel facility to conduct flow visualization tests on the actual trailer mounted system.

Part 2: Trailer Mounted Configuration

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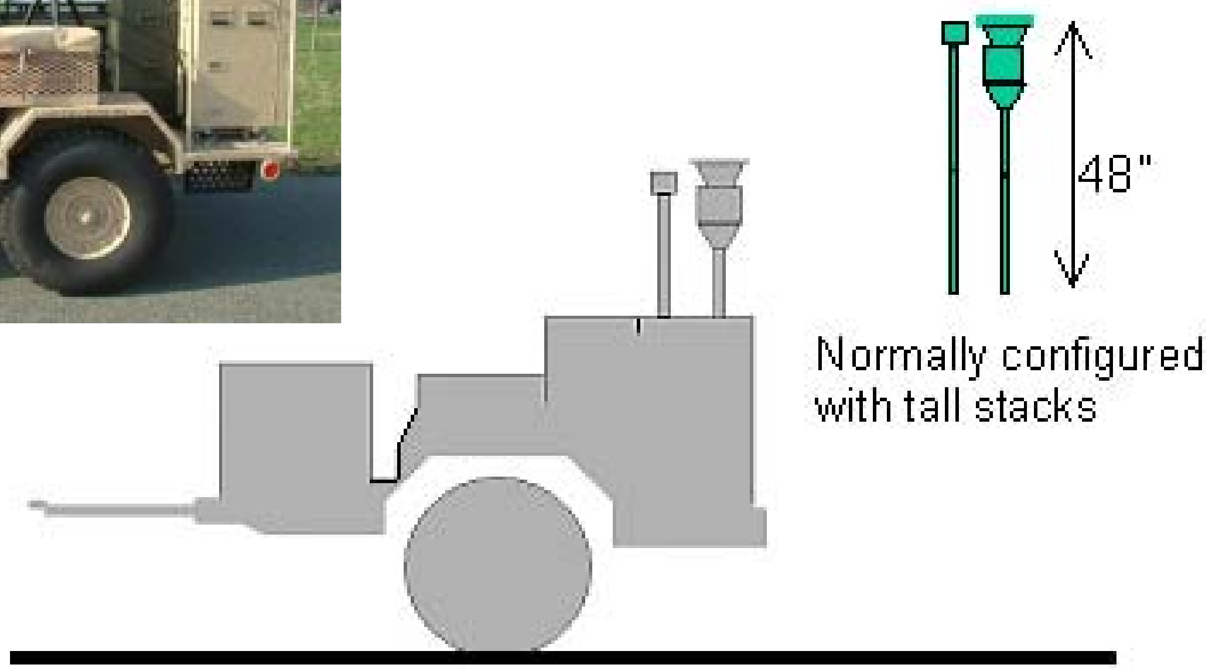
Trailer Mounted Configuration



JBPDS Trailer Mounted Configuration

•Note that the trailer mounted version employs 24-inch extensions to raise the inlet intake height.

•The smaller size of the trailer version also permits the use of the ECBC breeze tunnel facility to conduct flow visualization tests on the actual trailer mounted system in a controlled wind environment (in contrast to the marginally successful open field testing (uncontrolled environment) of the vehicle version)

•A 20% scale model of the trailer version was rapid prototyped from the actual drawings. Flow visualization using smoke wand was performed with the model at various orientations to the wind. Worst case orientations were identified and flow to inlet intake area characterized.

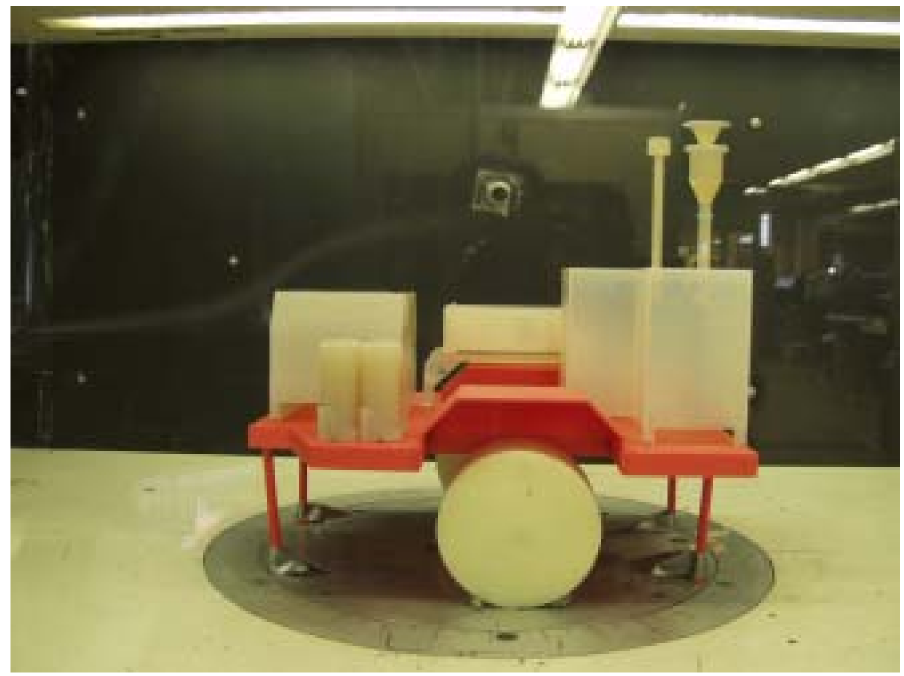
•Tests were repeated with the trailer draped in simulated camouflage netting to assess the flow situation in the event that users deployed camouflage.

•Flow over full scale JBPDS was then evaluated in breeze tunnel in worst case orientation identified in the wind tunnel tests, with and without actual camouflage netting. Used the netting from the JBPDS vehicle configuration. This supplements and validates the flow fields visualized in the wind tunnel tests.

Trailer Mounted JBPDS Flow Study

Flow visualization over scale model in ECBC Wind Tunnel

wind tunnel facility and test set-up



20% scale model in wind tunnel

Note: Inlet Stacks are modeled without extensions (26-inches high in full scale)

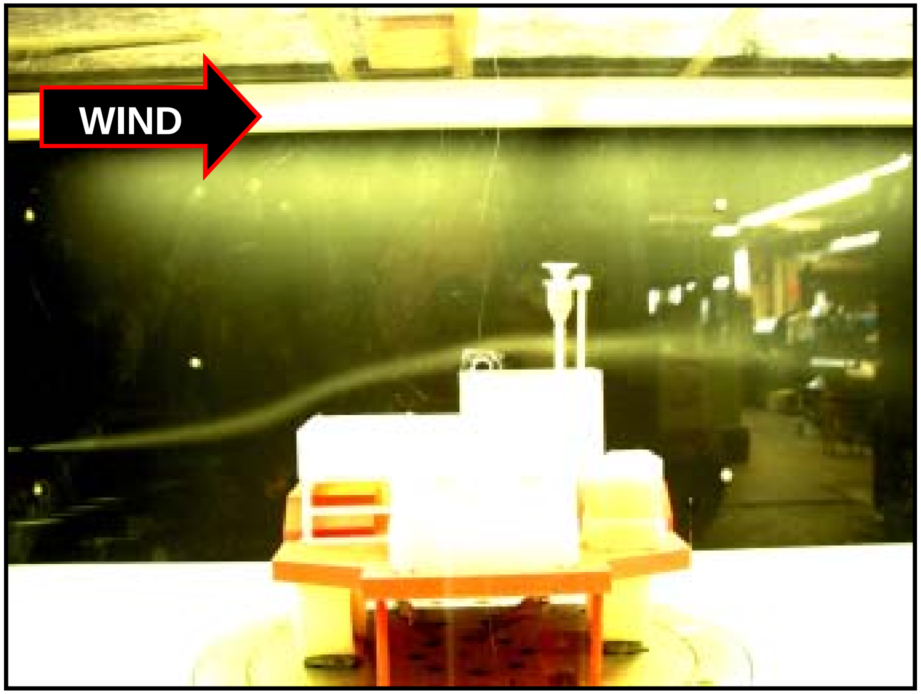
Trailer Mounted JBPDS Flow Study

Edgewood Chemical Biological Center

Flow visualization over scale model in ECBC Wind Tunnel

Model was rotated through 360-degrees, two orientations are shown here

High contrast photos of smoke visualization of flow over trailer



Trailer right side into wind orientation

Trailer forward into wind orientation

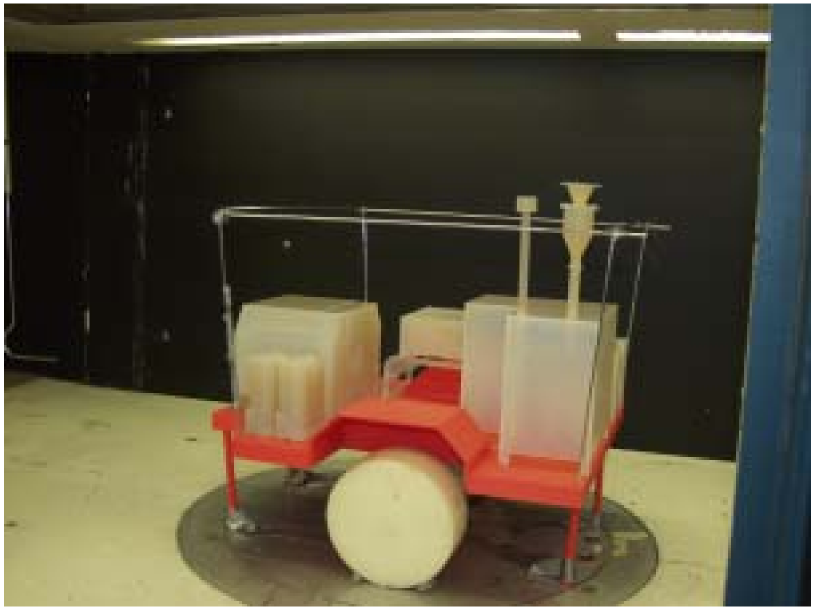
Trailer Mounted JBPDS Flow Study

Trailer Model with Camouflage Netting

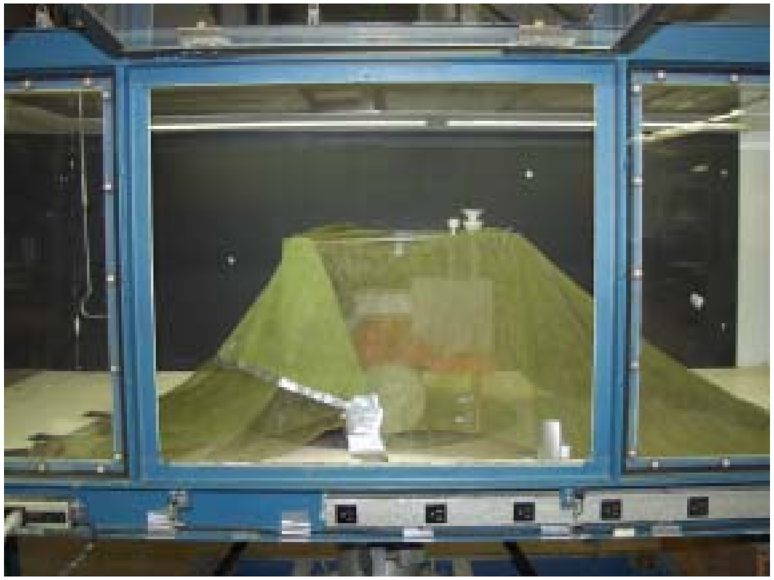
Netting is draped over framework and deployed in fashion similar to photos obtained of actual trailer cloaked in General Dynamics camo material. Inlets (without stack extensions) protrude through net.

Camo netting porosity is hard to model accurately so two different porosity levels were modeled by layering the netting on the model

Trailer draped in one layer of fine weave netting



Trailer with framework

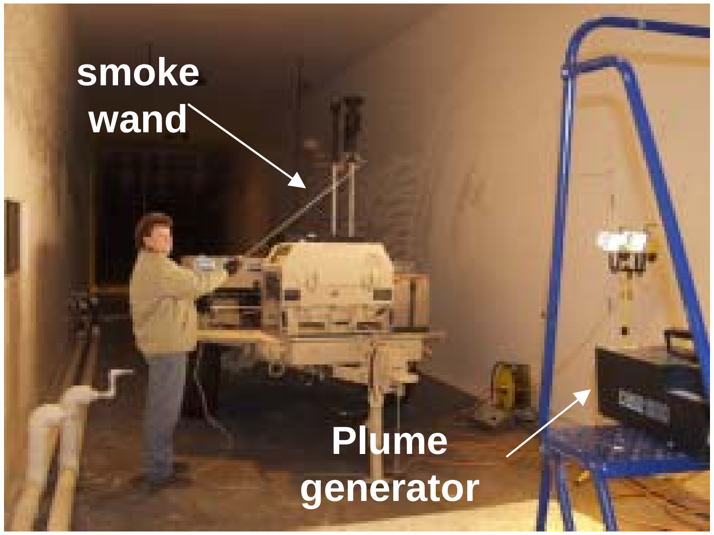


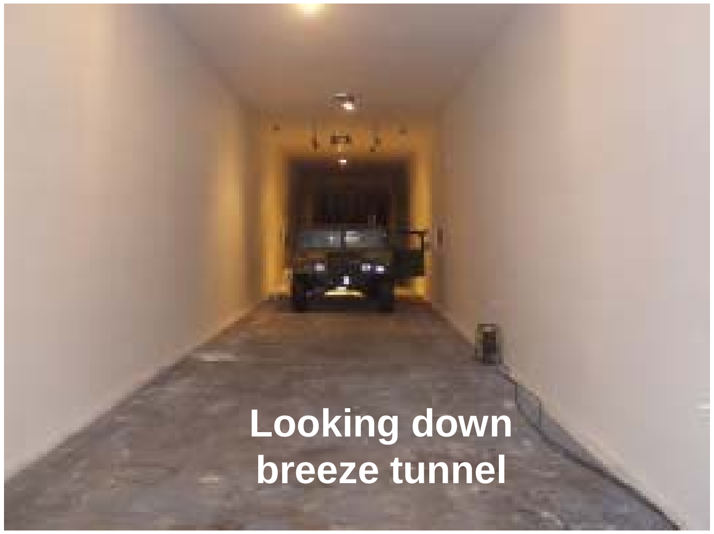
Trailer draped in fine weave and heavy weave netting

Trailer Mounted JBPDS Flow Study

Flow visualization over actual trailer in ECBC Breeze Tunnel

A full scale trailer mounted version of JBPDS was placed in the ECBC Breeze tunnel facility. Wind tunnel testing of scale model indicates that tongue forward orientation is most likely to cause flow problems therefore all testing was performed with the trailer facing forward. This will be defined as the 12-o'clock position. (most photos depicted looking downstream at trailer) Flow over the trailer was visualized using a smoke wand and a theatrical smoke plume generator

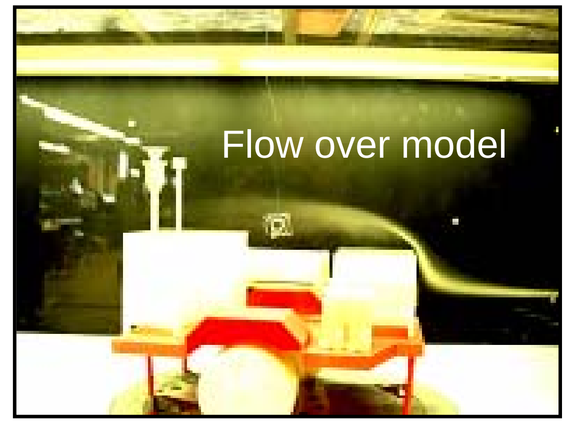


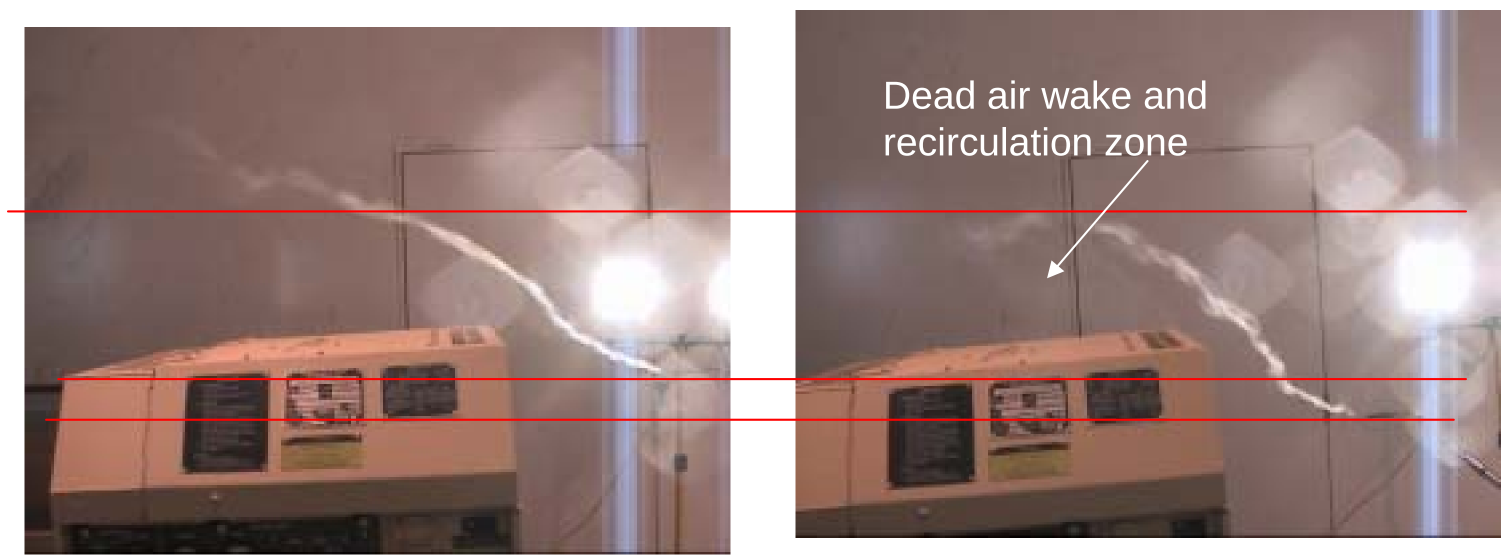


Trailer Mounted JBPDS Flow Study

Flow visualization over actual trailer in ECBC Breeze Tunnel

Streamlines over blunt leading edge of trailer objects visualized using smoke wand. The two photos show the deflection of the flow up and over the blunt object and, as the wand is lowered, the height of the dead-air recirculation zone over the surface of the blunt object. This is useful to compare to the flow over the scale model in the wind tunnel testing.



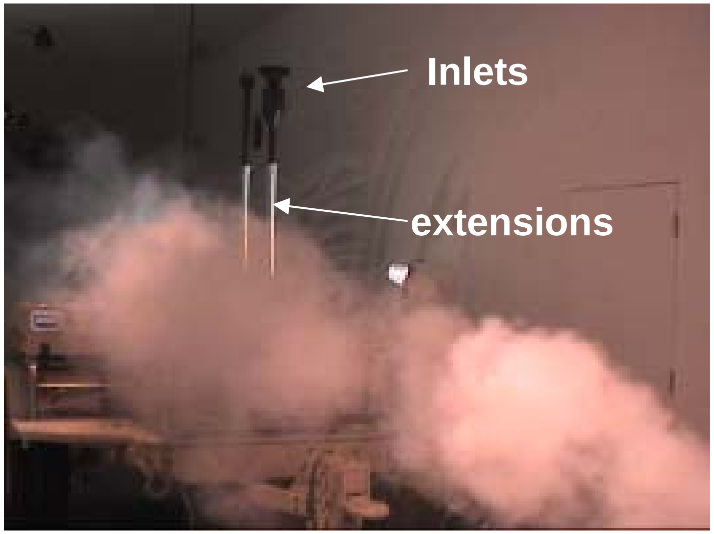


Trailer Mounted JBPDS Flow Study

Flow visualization over actual trailer in ECBC Breeze Tunnel

Smoke plume from a theatrical smoke generator is released upstream of trailer from a vertical height of 54-inches. Plume encounters blunt shape of trailer objects and rises. Plume passes inlet location at a height no greater than the maximum height of the inlet extensions. Intake of inlet is at least 24-inches above this flow field.

Test conditions: T=40 F,
Wind Velocity ~ 6 mph



Part 2. Summary & Comments

- Tests were conducted on 20% scale model in wind tunnel and actual full scale trailer mock-up in breeze tunnel. Good agreement between observations made in wind tunnel and breeze tunnel.
- Tests were conducted with and without camouflage netting draped over trailer.
  - *Without camouflage canopy*: the flow to the inlet intake area is fine, even without the inlet extensions in the worst case orientations. The trailer and mounted equipment has very little influence on effective sampling height.
  - *With camouflage canopy*: The flow to the inlet intake area is fine when extensions are used. Effective sampling height is about 8-inches lower than the actual inlet height due to streamline deflection upward to inlet as flow passes over canopy
    - Significant flow penetrates canopy, and accumulates under the netting. Some of the flow is pulled up through the top of the canopy and rolls along the net surface to the inlet site. Flow remains attached to top of canopy. If configured without inlet extensions it would still aspirate the target aerosol, however it would also probably take in a lot of contaminant from the trailer area, equipment and dust from the ground

Part 2. Summary & Comments

Recommendations:

- Inlet extension use is recommended when the system is draped in camouflage.
- Inlet extension use is optional when the trailer is “uncloaked” or normally configured. Extension use would neither enhance nor adversely affect performance.

Conclusion

Flow fields around two JBPDS configurations were evaluated for pertinence to system performance. Used 3 techniques: models in wind tunnels, full scale hardware in breeze, and Computational Fluid Dynamics (CFD)

- Wind tunnel & scale models: good visualization, have to be aware of scaling effects
- Full scale: can evaluate effect of things that are tough to model (camouflage netting) but harder to perform visualization, need big test facility with quality air flow
- CFD: Great for detailing flow. Results depend on skill of the user, especially with fine detailing of flow. Can be a time-saver or a time-sink, for example the modeling of camouflage net could be a large study

Conclusion

Flow field around nearby objects can affect detection system performance, this study observed various effects:

- Effective Sampling heights were identified
- Effects of cloaking nets were investigated
- Proximity to inlets to various flow fields were detailed, speculated on implications

  reiteration of the main findings:

  - Inlet intakes could be in or on boundary of recirculation zones
    - May have effect on system due to fluctuating aerosol concentrations and trapping/bleeding of ground dust/background to intakes
    - Contaminants/ interferents/ dust/ exhaust downwind from system can be drawn back to system by reverse flow in wakes

Conclusion

Main Point:

Be aware of the nature of the flow field around your sampler. You can then account for effect, mitigate the effect, or perhaps use it to advantage.